LA-UR 89-1351

C.1

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36.

TITLE: "The Los Alamos National Laboratory Spallation Neutron Sources"

AUTHOR(S): P. W. Lisowski
C. D. Bowman
S. A. Wender
G. J. Russell
Los Alamos National Laboratory
Los Alamos, NM 87545

SUBMITTED TO: Nuclear Science and Engineering

The Los Alamos National Laboratory Spallation Neutron Sources

P. W. Lisowski, C. D. Bowman, G. J. Russell, and S. A. Wender

University of California, Los Alamos National Laboratory, Physics Division, Los Alamos, New Mexico 87545

Abstract - *In this paper we describe two neutron sources used for nuclear physics research at Los Alamos National Laboratory. Both are driven by the 800 MeV proton beam from the Los Alamos Meson Physics Facility (LAMPF). The Los Alamos Neutron Scattering Center (LANSCE) is based on a moderated source which provides useful neutrons from sub-thermal energies to approximately 100 keV, and is used primarily for condensed matter research. The Weapons Neutron Research (WNR) facility uses a bare target which is designed to produce fast neutrons with energies from 100 keV to 800 MeV. We will describe the characteristics of these sources, ongoing research programs, and potential directions for both the facility and the physics program with emphasis on research relevant to international fusion technology needs.*

I. INTRODUCTION

The two spallation neutron sources at Los Alamos National Laboratory offer extraordinary potential for nuclear physics research. Together they provide intense pulsed neutron beams for time-of-flight research over eleven decades of energy. Although there are other spallation sources using a medium energy proton beam as a driver, Los Alamos has the only spallation source with an extensive neutron nuclear physics research program underway. The purpose of this paper is to describe both facilities, the characteristics of their neutron spectra, ongoing research programs, and potential directions for both the facility and the physics program. The potential exists for a broad range of experiments closely related to fusion technology; this paper will stress those contributions.

II. SPALLATION NEUTRON SOURCES

Facilities such as the ones at Los Alamos using medium energy proton beams incident on heavy metal targets take advantage of spallation to enhance neutron production over that possible at lower energies. When protons of several hundred MeV bombard a thick target of heavy nuclei, both neutrons and other spallation products are produced. Spallation products react with other target nuclei producing a cascade which generates a broad neutron spectrum with more neutrons emitted than bombarding protons. Modelling spallation neutron production for thick targets is complicated by the facts that both neutron production and subsequent transport are equally important. Often the Intra-Nuclear-Cascade model coupled to one or more transport codes is utilized[1]. For example, at 800 MeV we calculate that about 20 neutrons per proton are produced in the LANSCE target.

For time of flight experiments, the structure of the neutron beam must be tailored to suit the needs of the experiment. Pulses must be narrow enough to provide suitable energy resolution and separated enough in time to avoid interference with lower energy neutrons produced in the previous burst. Those requirements are usually quite different for low and high-energy neutrons. Low energy neutron experiments generally prefer burst widths from one to one hundred microseconds and pulse separations of milliseconds; while high energy experiments need both widths and spacings three orders of magnitude smaller. Furthermore, although neutrons for high energy research may be generated directly by spallation, there is little direct production of low-energy neutrons, necessitating the use of a moderator for those experiments. At Los Alamos, there are separate target facilities for the different energy regimes.

III. LAMPF ACCELERATOR

The implementation of the spallation source concept at Los Alamos is based on the LAMPF three-stage high-intensity proton accelerator[2]. At LAMPF, hydrogen ions are produced and accelerated to 750 keV in any of three Cockcroft-Walton accelerators, one providing H^+ , one H^-, and one polarized H^- ions. The beams are combined, chopped and bunched to produce the required time structure, and injected into a 62-m long drift-tube linac operating at 201.25 MHz. The drift-tube linac accelerates beams of both positive and negative ions to an energy of 100 MeV using opposite phases of the driving RF. The final accelerator stage consists of a 48 sector side-coupled-cavity linear accelerator operating at 805 MHz. The production beam from LAMPF has a macroscopic repetition rate of 120 Hz. These macropulses, are approximately 800 microseconds long. Within each macropulse there is a microstructure consisting of pulses with a time width of about 60 ps, separated by 5 ns. The number of protons in a micropulse is about 1×10^8 for H^- beams and 5×10^8 for H+ beams. LAMPF can deliver either H^+ or H^- with up to three different energies on different macropulses.

IV. PSR/LANSCE

The layout of the PSR/LANSCE facility is shown in Fig. 1. There are two experimental areas. The inner one, denoted as ER-1 surrounds the target area and is used for experiments requiring the highest intensity. The outer area, denoted as the neutron scattering experimental hall, or ER-2, is a new 32,000 ft^2 addition completed in 1988 and used for spectrometers requiring longer flight paths.

The LANSCE target is optimized to produce thermal and epithermal neutrons for research using the time of flight technique . At those energies, the direct proton beam has a peak intensity too low to effectively use short pulses which could be produced by beam chopping alone. The LAMPF beam is therefore compressed by a Proton Storage Ring[3] (PSR). The PSR accumulates the 800 MeV proron beam for approximately 450 μs and extracts that beam in a single 270-ns burst. This is accomplished by chopping the beam before injection into LAMPF into a sequence of 250-ns long bursts separated by 110-ns gaps. Because the the ring is designed to have a 360-ns circulation time for 800 MeV protons, that train of pulses can then be stacked within the PSR. The first of the proton bunches executes about 1250 turns before extraction. At present the PSR is delivering 60 μA at 20 Hz; however, an upgrade is underway which will increase the current to 100 μA.

LANSCE has a split target-moderator-reflector-shield (TMRS) assembly[4] located in the center of a 3.7-m thick laminated iron-concrete biological shield that allows up to 200 μA of 800 MeV proton beam on target with low enough radiation leakage that experimenters can occupy the experimental area. As shown in Fig. 2, neutrons from the upper target (10-cm Diam. x 7.25-cm long tungsten) and lower target (10-cm Diam. x 27-cm long tungsten) drive a moderator-reflector configuration that allows twelve flight paths to operate simultaneously with three flight paths viewing each 13-cm by 13-cm moderator. Of these, three are ambient temperature water moderators; two of which are heterogeneously poisoned at 2.5 cm with gadolinium and with a cadmium decoupler/liner, and one is heterogeneously poisoned at 1.5 cm with gadolinium with a boron decoupler/liner. The fourth moderator is liquid para-hydrogen operated at about 20^{o}K. The calculated neutron yields at the moderator surface from those moderators is shown in Fig. 3. There the spectrum may be seen to have a Maxwell-Boltzmann shape at thermal and to be proportional to $1/E_n$ in the epithermal range. The neutron intensity available for a given experiment is strongly dependent on the parameters of that experiment and the flight path in use (filters in the beam, moderator surface and type viewed, flight path, etc.); for the high-resolution and high-intensity water moderators now used by nuclear physics experiments, the measured intensity is approximately given by $\Phi = 2.8 \times 10^3 / E_n$ (n/eV/cm^2/μA/sec) and $\Phi = 3.3 \times 10^4 / E_n$ (n/eV/cm^2/μA/sec) for the high-resolution and high-intensity moderators with 141 and 131 cm^2 respective surface areas viewed at 31.8 and 9 m flight path locations. The calculated time spread of neutron pulses from LANSCE for thermal and epithermal neutrons is dominated by the moderation time in the TMRS and given approximately by $\Delta t = 7.1/\sqrt{E_n}$ μs. For energies in the keV region, the time spread is governed by the pulse width from the PSR which is approximately an isoceles triangle with a base of 250 ns.

IV.A. LANSCE EXPERIMENTAL PROGRAM

The LANSCE facility will include 16 flight paths when fully instrumented. Most of these flight paths will be devoted to condensed matter research using neutron scattering techniques. Those studies could include the investigations of materials properties of interest to the fusion program. Several of the flight paths are used in basic and applied neutron nuclear physics research. The high average neutron intensity combined with low pulse rate and short pulse at LANSCE make it useful at thermal and epithermal neutron energies, and up to 100 keV in favorable cases where high energy resolution is not required. Virtually any aspect of neutron nuclear physics in this energy range may be studied with this source. However the present nuclear physics research program concentrates on three general subjects which are discussed separately below.

IV.A.1. Nuclear Cross Section Measurements on Unstable Targets

The high instantaneous neutron production rate of the LANSCE neutron beam is an ideal situation for the study of nuclear cross sections of radioactive nuclei. Because the high intensity allows measurements with very small samples, the associated radioactivity is reduced to a low level. Furthermore, the very low duty cycle strongly discriminates against any background induced in the detector by the radioactive sample. Table I gives a comparison[5] at 30 keV of the LANSCE neutron flux and figure-of-merit for unstable target measurements with that available at the Karlsruhe Van de Graaff facility[6] and at ORELA[7]. In this comparison, the duty factor (D.F.) was taken for a 5 keV neutron window corresponding to the 17% keV resolution of LANSCE, with 100 mA of proton beam on target.

Capability now exists for neutron-induced charged-particle and neutron-capture cross section studies. Sample sizes might be typically in the hundreds of nanograms range with half-lives as short as 30 days under favorable conditions. The first experiment in this series was a measurement[8] of the (n,p) reaction on 53-day ^{7}Be. The reaction protons were detected by a surface barrier detector placed outside of the neutron beam. The 90-nanogram sample was in the form of an 0.32 cm diameter deposit on a thin aluminum substrate at a flight path of about seven meters.

The capture measurements will use a 30 x 30 x 30-cm^3 BaF_2 scintillator for detection of gamma rays following neutron capture. The eight crystals for this detector are on hand and the detector is now being assembled. The flight path for the capture detector will be about nine meters long. Both the charged-particle and the capture gamma-ray detector detector assemblies are located on the same flight path and arranged for easy switching between the (n,p) and the (n,γ) experiments. Useful capture measurements should be possible up to 50 keV. For many nuclei this includes a large part of the resonance range and it also allows for a maxwellian averaged cross section near 25 keV for stellar processes. Measurements such as these could be performed to provide information relating to the burn-up of radioactive nuclei produced in fusion reactors.

IV.A.2. Polarized White Neutron Beam

The usual spectrum of polarized neutron research possible with a white epithermal neutron beam is greatly broadened by the high intensity polarized beam recently brought on line at LANSCE. The polarized neutrons are produced by transmission through a polarized proton filter. The filter is 10 cm^2 in area and produces a 50% polarization with a transmission of 0.2. The polarization is in the longitudinal direction and extends from 0.1 eV to about 50 keV. Below 0.1 eV even larger polarization is present, but at substantially lower intensity. The direction of the neutron spin may be changed using a spin flipper up to 1000 eV. The polarizing filter is located at 6.5 meters from the moderator. Three detector/experiment positions are located at 11, 25, and 55 meters.

The major research program using polarized neutrons presently is the study of parity violation in p-wave neutron resonances[9]. Parity violation is enhanced in these resonances by a factor of 10^4 over that observable in the nucleon-nucleon system. This enhancement along with the high statistical accuracy available with the intense beam makes possible studies of parity violation over a wide energy region in a single nucleus and over a wide range of nuclei. Since parity violation arises from the weak force, the detection of parity violation should provide our first handle on the influence of the weak force in nuclei.

Of perhaps even greater interest is a developing program[9] of tests for time reversal invariance violation (T-violation). Enhancements equivalent to those found in parity violation are also expected for T-violation in p-wave resonances. These experiments are more complex requiring both a polarized beam and target.

IV.A.3. Strong Transient Analysis

Analysis of the effects on materials of applied strong transients using a single LANSCE pulse appear to be possible with nuclear techniques. Measurements can be made of the position in energy and the width of neutron resonances for information on sample velocity and temperature. Also, the study of Bragg edges will give information on the material phase, its temperature, the strain, etc. The time domain for such studies extends over the time range from 10^{-6} to 10^{-2} seconds. These measurements require the use of current mode (rather than the usual pulse mode) neutron detection[9] which was developed for the parity violation experiments. Planning of the first examples of these measurements is under way at the present writing.

V. WNR

The WNR facility consists of two target areas as shown in Fig. 4. The first of these, Target-2, is a low current area shielded for up 100 nA of 800 MeV proton beam. The newest addition to the WNR is the area labelled Target-4. Completed in June of 1988, Target-4 is designed to provide an intense white neutron source extending from below 0.1 to above 750 MeV. The biological shield for this area is designed to handle up to 20 μA of proton beam. As an illustration of the high efficiency with which spallation sources such as the WNR Target-4 produce fast neutrons, Fig. 5 compares the Target-4 neutron yield at 30^{o} as a function of energy for several different reactions which are used as white neutron sources[10].

The proton beam delivered to the WNR facility consists of LAMPF macropulses which are chopped and bunched before acceleration to give micropulses with about 3 x 10^8 p. These pulses are separated typically by one to two μs depending on the requirements of the experiments underway, but spacings of many microseconds are possible. Because of momentum dispersion in the beam, the proton pulse spreads in time as it drifts from the exit of the accelerator; at 800 MeV it is about 150 ps wide at the WNR target. At energies below 800 MeV, this time spreading increases, but it is possible to recover a narrow pulse by using one or more accelerator cavities to rebunch the beam[11]. The anticipated operating mode at WNR is with 70 macropulses per second. In that case at a pulse separation of 1 microsecond, the proton current would be 2.5 microamperes with 52,500 micropulses/second. Because of pulsed magnet limitations in the LAMPF beam transport, the facility is presently limited to a maximum of 60 Hz, with routine operation at 40 Hz, or 32,000 micropulses/second.

V.A.1 Target-2

A plan view of Target-2 and Target-4 are shown in Fig. 6 along with their respective experimental areas. Fig. 7 shows a cross sectional view of both target areas. Target-2 is designed to reduce the background from scattered neutrons by having a low-mass floor and a 6-meter wall-to-center spacing. Because the beam pipe may be removed, this area allows access to the proton beam. When Target-4 is in operation, the LAMPF proton beam is transported through Target 2 and into a magnet which bends beam 8.25° up to Target-4. This magnet can also bend the proton beam down 16° to a beam stop below Target-4.

The Target-2 experimental area provides the capability of performing experiments with the proton beam at energies between 113 and 800 MeV. In the past, radiation damage effects, (p,γ), (p,n) and (p,z) reactions have been studied in Target-2. Experiments may be set up either inside Target-2 or in detector stations located on several flight paths outside Target-2. Detector stations have been implemented at the following angles and distances: 7.5^{o}-50 m, 15^{o}-30 m, 30^{o}-30 m, 60^{o}-60 m, 120^{o}-60 m, and 150^{o}-30 m. A versatile 1-m diameter evacuated scattering chamber can be located in the center of the room for proton-induced charge particle reaction studies.

A 250-m flight path has been developed at 0^{o} with respect to the incident proton beam. By moving thin samples along the proton beam trajectory in the chamber of the magnet which bends the beam up to Target-4, it is possible to measure cross sections and angular distributions of neutrons following (p,n) reactions with good energy resolution. Angular distributions may be obtained from 0^{o} to 8.25^{o} when the beam is being transported to Target-4 or from 0^{o} to 16^{o} when the beam is directed to the beam stop.

V.A.2. Target-4

The Target-4 neutron production cell consists of a 3-cm diameter, 7.5-cm long water cooled tungsten target suspended at the center of a 1.8-m diameter by 1.2-m high vacuum chamber and surrounded by a massive shield with penetrations for neutron flight paths at 90^{o} right (R), 90^{o} left (L), 30^{o} R and L, 15^{o} R and L and 60^{o} R. Two target mechanisms are available in the vacuum chamber to allow easy changing of the production target.

The upper half of Fig. 8 shows a plan view of the neutron shield around Target-4 and the lower half gives a cross-sectional view. The shield has a central vacuum chamber surrounded by 0.5-m of solid iron with an additional 2-m of iron in the forward direction. In the other directions the shielding consists of a mixture of steel balls and magnetite concrete filling the inner volume. The density of this mixture is approximately 5.6 g/cm^3. Construction was completed in June of 1988.

Table II lists the angles, lengths and present use of the neutron flight paths. As seen from Fig. 7, the neutron flight paths from Target-4 are approximately one meter above ground while the flight paths that look toward the center of Target-2 are approximately one meter below ground level.

In medium-energy proton reactions, neutrons of the highest energies are produced mainly in the forward direction. This feature allows experiments at WNR to tailor the neutron spectrum to the experiment to some extent. Fig. 9 shows neutron spectra for the tungsten target calculated using the HETC-MCNP code package[1] for the four neutron-emission angles available from Target-4. At 15^{o}, the neutron spectrum extends to nearly 750 MeV, whereas at 90^{o} the high-energy neutrons are suppressed by the reaction mechanism and lower-energy neutrons are attenuated less by the target material, resulting in nearly a factor of two more flux below 20 MeV. Additional source spectrum tailoring could be done by choosing different target elements. As the first target, tungsten was a good compromise giving good low and high energy neutron production. Measurements are currently underway to verify the accuracy of those calculations. Preliminary results indicate that the shapes of the calculated and experimentally determined spectra agree well below 20 MeV but that measured values are higher than calculated above 20 MeV. Below 20 MeV, where the ^{235}U(n,f) reaction can be used as a standard, the measured and calculated values agree to within about 20% absolute. Fig. 10 shows calculated spectra at 30^{o} for targets of the same size as the present tungsten one. Copper would offer a much more uniform distribution with energy, useful for experiments which would like to minimize the low/high energy neutron ratio. A depleted-uranium target would increase the overall production by about 35%, with the majority of those neutrons occuring below 20 MeV.

V.B. WNR EXPERIMENTAL PROGRAM

When fully instrumented, the WNR facility will have seven flight paths from Target-4 for neutron experiments and six flight paths from Target-2 for studying proton-induced reactions. These will all be used in the study of fast-neutron reaction and scattering mechanisms. Until now, the neutron intensity available above a few MeV has been too low to consider all but the simplest neutron induced reaction studies. However, with the advent of the WNR Target-4 source, exclusive experiments with incident neutrons up to several hundred MeV have become possible. These studies will greatly enhance our knowledge of a broad range of neutron-induced phenomena such as fission, photon production and charged particle production. The broad energy range at WNR is important not only because it covers the regime directly interesting to the fusion community, but because it extends well beyond providing important benchmark information for theoretical modeling and data evaluation. At present there are active experimental programs in many diverse areas ranging from defense related radiation damage studies to neutron-induced pion production. In the following section we will highlight three experiments illustrating the value of this facility to fusion technology.

V.B.1. Gamma Ray Production Measurements

This type of measurement has been used[12] to provide neutron-induced photon production cross sections on several materials. Those data are needed in a variety of fusion technology applications ranging from shielding design studies to radiation damage and heating estimates. At the WNR two classes of gamma-ray production measurements are presently performed. The first emphasizes high energy gamma rays and uses an array of five 7.6 cm Diam. x 7.6 cm long BGO detectors. The second class of gamma-ray measurements are performed with a Ge(Li) detector which provides excellent gamma-ray energy resolution. Both systems take data into two dimensional arrays of gamma-ray pulse height vs. neutron time of flight. By taking projections, pulse height spectra for each neutron energy bin may be obtained. Using this technique reaction cross sections such as (n,n'), (n,2n), (n,3n), (n,p), and (n,α) to particular states may be measured over a wide energy range.

V.B.2. Fission measurements

The program currently underway[13] is focussed on improving the ^{235}U(n,f) cross section standard and determining precise data relative to ^{235}U for other actinides, including ^{232}Th, $^{233,234,235,236,238}U$, ^{237}Np, ^{239}Pu. These data are obtained at a flight path of 20-m using a fast parallel plate ionization chamber containing multiple fission samples and a proton recoil flux monitor.

V.B.3. Charged-particle production

The bulk of experimental data on charged particle production cross sections has so far been obtained only near 14 MeV. In the studies now underway at Target-4, (n,p) and (n,α) reaction cross sections, angular distributions, and charged-particle emission spectra are being measured from threshold to about 30 MeV neutron energy for a variety of nuclear targets. Although the principal goal of these measurements is to determine level densities, the double-differential cross section excitation functions which are being obtained will be useful to the fusion community as well. These studies use an evacuated reaction chamber and charged-particle detection array at flight path of 10-m and 90° to the production target.

VI. FUTURE FACILITY ENHANCEMENTS AND CONCLUSIONS

The performance of LANSCE and WNR as complementary pulsed neutron sources is much superior to the electron linacs traditionally used in this research as far as the thermal/epithermal and the range above a few MeV. In the domain of lower keV to a few MeV, the performance is comparable. Improved performance over the entire range is possible by making improvements to the proton beam bunching system to give WNR the same current now delivered but with a much wider pulse spacing. Studies are underway to investigate such an upgrade. At LANSCE the PSR is now supplying proton pulses at an average current of 60 μA and a pulse rate of 20 Hz. Even better performance is expected through an improvement program presently under way to bring the average current up to 100 microamperes with greater than 70% overall beam availability.

In addition to the neutron research associated with the LANSCE target, consideration is being given to another target station which would provide direct access to the PSR beam for a variety of experiments requiring single pulses or a slow (< 1 Hz) pulse rate. An example would be driving a lead slowing-down spectrometer with proton pulses to give neutron intensities four orders of magnitude greater than has been previously accomplished.

The experimental capability of the WNR facility can be substantially extended. In 1990 the 40-m flight path at 30^{o}L will be lengthened to 350 m and a total cross-section program performing measurements which will cover the energy range from below 20 MeV to near 750 MeV. Recent calculations have shown that there are two promising methods for production of polarized neutrons with useable intensities at Target-4. At energies in the few-MeV range, scattering from ^{4}He appears feasible; at higher energies and longer flight paths, Mott-Schwinger scattering appears to be the best candidate. Such measurements would open a wide array of interesting neutron physics ranging from few-nucleon polarization studies to polarization phenomena in elastic and inelastic neutron scattering.

The combined LANSCE/WNR neutron sources have opened up prospects for experiments which were totally impractical only a few years ago, revitalizing the field of neutron nuclear science which had become stagnant during a twenty year period of nearly static neutron intensity. The LANSCE/WNR staff require outside participation to fully use these new sources and welcome suggestions for collaborations across the full spectrum of basic and applied science which can be studied using these facilities.

TABLE I

Comparison of Neutron Flux at 30 keV for Measurements on Radioactive Samples at Different Facilities

Facility	Flight Path (cm)	Flux (cm^{-2} s eV^{-1})	F.O.M (Flux/D.F.)
Van de Graaff	10	13	3.3×10^3
ORELA	1000	0.5	1.6×10^3
LANSCE	700	25	1.0×10^7

TABLE II

WNR Target-4 Flight Paths

Angle	Length (m)	Experiment
90L	8	0 - 30 MeV (n,p), (n,α)...
30L	40	(n,π), detector development
15L	90	30 - 350 MeV (n,p), (n,d)
15R	8	(n,xγ), (n,γ)
30R	---	Not implemented
60R	20	1 - 400 MeV (n,f)
90R	7	Facility neutron monitor

REFERENCES

1. R. E. PRAEL, "High-Energy Particle Monte Carlo at Los Alamos," Monte Carlo Methods and Applications in Neutronics, Photonics and Statistical Physics, P. 196, R. ALCOUFFE, R. DAUTRAY, A. FORSTER, G. LEDANOIS, and B. MERCIER, Eds., Verlag Publisher, Berlin/Heidelburg, 1985.

2. J. C. ALLRED AND B. TALLEY, "LAMPF," Los Alamos National Laboratory Report, LA-UR-87-327, January, 1987.

3. G. P. LAWRENCE, 1987 Particle Accelerator Conference, Washington, D.C. March 16-19, 1987

4. G. J. RUSSELL, H. ROBINSON, G. L. LEGATE, R. WOODS, E.R. WHITAKER, A. BRIDGE, K. J. HUGHES, AND R. D. KNEEF, "The LANSCE Target System," Proc. Conf. Ninth Meeting of the International Collaboration on Advanced Neutron Sources (ICANS-IX), Villigen, Switzerland, September 22-26, 1986, ISBN 3-907998-01-4 (July 1987).

5. F. KAEPPLER, "Comments on the PSR Proposal: Neutron Capture Studies on Radioactive Samples", private communication, November, 1986.

6. H. BEER AND F. KAEPPLER, "Neutron Capture Cross Sections on 138Ba, 140,142Ce, 175,176Lu, and 181Ta at 30 keV: Prerequisite for Investigations of the 176Lu Cosmic Clock", Phys. ReV. C21, 534 (1980)

7. J. W. T. DABBS, "Neutron Cross Section Measurements at ORELLA", Proc. Conf. Nuclear Cross Sections for Technology (1979 Knoxville), Knoxville, Tennessee, U.S.A., October 22-26, 1979 P 929, U.S. Department of Commerce, Washington, D.C. U.S.A.

8. P. E. KOEHLER, C. D. BOWMAN, F. J. STEINKRUGER, D. C. MOODY, G. M. HALE, J. W. STARNER, S. A. WENDER, R. C. HAIGHT, P. W. LISOWSKI, and W. L. TALBERT, "^{7}Be(n,p)^{7}Li Total Cross Section from 25 meV to 13.5 keV", Phys. Rev., C37, 917 (1988).

9. C. D. BOWMAN, J. D. BOWMAN, V. W. YUAN, P. HERCZEG, J. SZYMANSKI, R. N. MORTENSON, J. M. ANAYA, H. POSTMA, P. P. J. DELHEIJ, O. K. BAKER, C. R. GOULD, D. G. HAASE, G. E. MITCHELL, N. R. ROBERSON, X. ZHU, A. B. MCDONALD, K. P. COULTER, D. BENTON, B. TIPPINS, AND T. E. CHUPP, "Fundamental Symmetry Studies at Los Alamos Using Epithermal Neutrons", Proc. Conf. Fundamental Symmetries and Nuclear Structure (1988 Santa Fe), Santa Fe, New Mexico, U.S.A., October 12, 1988, p 1, World Sientific Publishing Co. Pte. Ltd. Singapore, China.

10. K. H. BOECKHOFF, "Electron Linac Based Pulsed White Sources for High Resolution Neutron Time-of-Flight Spectroscopy - Status and Perspectives," Proc. IAEA Advisory Group Meeting on Properties of Neutron Sources, Leningrad, USSR, June 9-13, 1986, p. 35, IAEA-TECDOC-410, Vienna, Austria.

11. J. B. McCLELLAND, D. A. CLARK, J. L. DAVIS, R. C. HAIGHT, R. W. JOHNSON, N. S. P. KING, G. L. MORGAN, L. J. RYBARCYK, J. ULLMANN, and P. LISOWSKI, Nucl. Instr. Meth., A276, 34 (1989).

12. P. RAMAKRISHNAN, G. E. MITCHELL, C. R. GOULD, S. A. WENDER, G. F. AUCHAMPAUGH, and R. C. LITTLE, Nucl. Sci. Eng., 98, 357 (1988).

13. P. W. LISOWSKI, J. L. ULLMANN, S. J. BALESTRINI, A. D. CARLSON, O. A. WASSON, N. W. HILL, "Neutron Induced Fission Cross Section Ratios for 232Th, 235,238U, 237Np, and 239Pu From 1 to 400 MeV", Proc. Conf. Nuclear Data for Science and Technology (1988 MITO), Mito, Japan, May 30 - June 3, 1988, p 97, Saikon Publishing Co. LTD, Tokyo, Japan.

FIGURE CAPTIONS

Fig. 1. The PSR/LANSCE Facility - the beam from LAMPF enters the PSR from the right.

Fig. 2. The LANSCE target-moderator configuration. The present arrangement has twelve flight paths viewing the flux-trap moderators. Future flight paths will either view wing or slab moderators which would be installed in the upper target position.

Fig. 3. Calculated neutron leakage current at the moderator surface for the LANSCE target-moderator.

Fig. 4. The WNR Facility - beam from LAMPF enters from the right.

Fig. 5. Thick-target neutron yields for different white-neutron source reactions.

Fig. 6. The layout of the WNR Facility. The proton beam enters from the top. Flight path shown as solid lines are above grade and are centered of Target-4, those shown as dashed lines are below grade and are centered on Target-2.

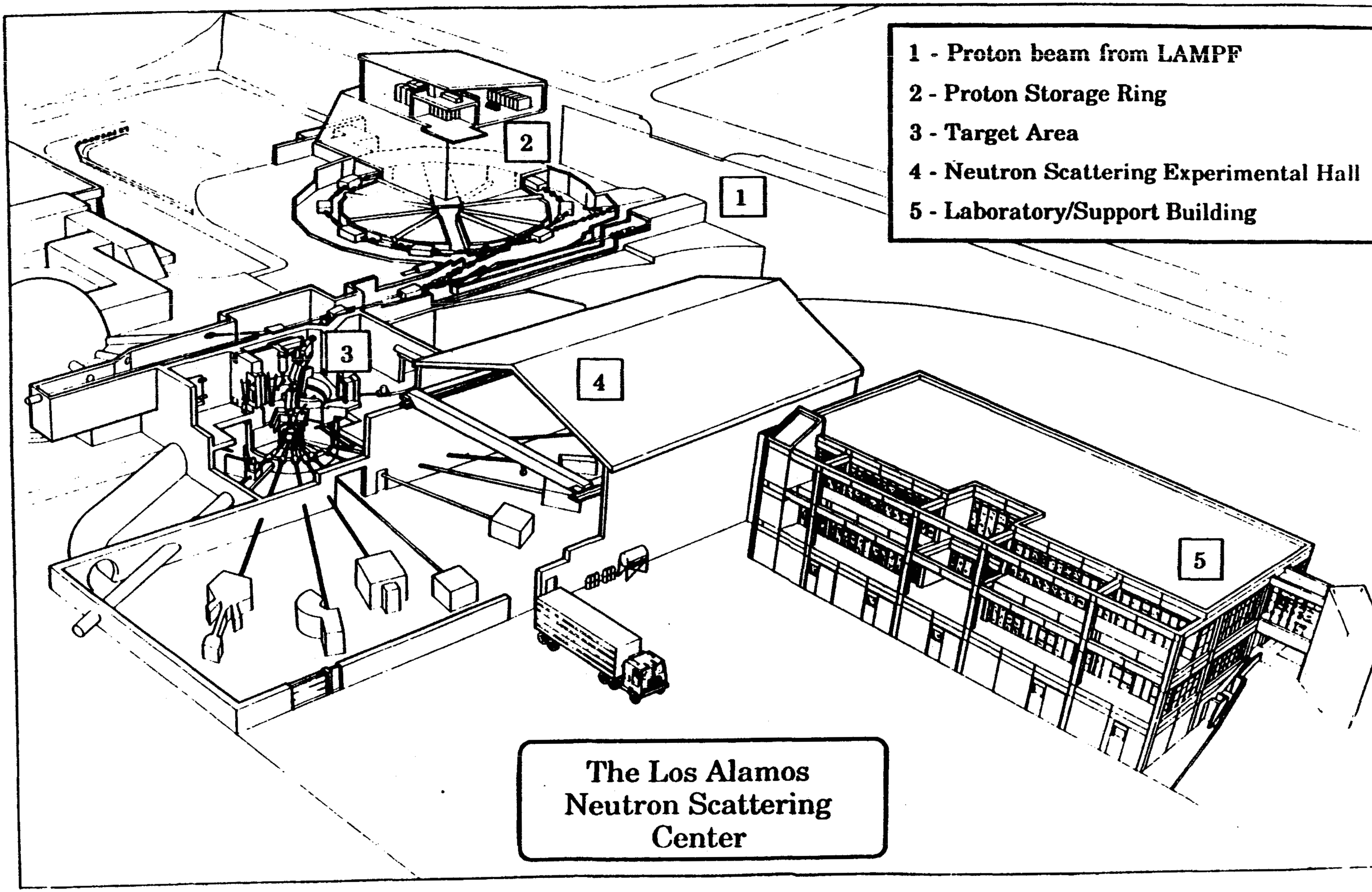
Fig. 7. Cross sectional view of the Target-4 and Target-2 experimental areas.

Fig. 8 The upper half shows a plan view of the neutron shield around Target-4; the lower half gives a cross-sectional view.

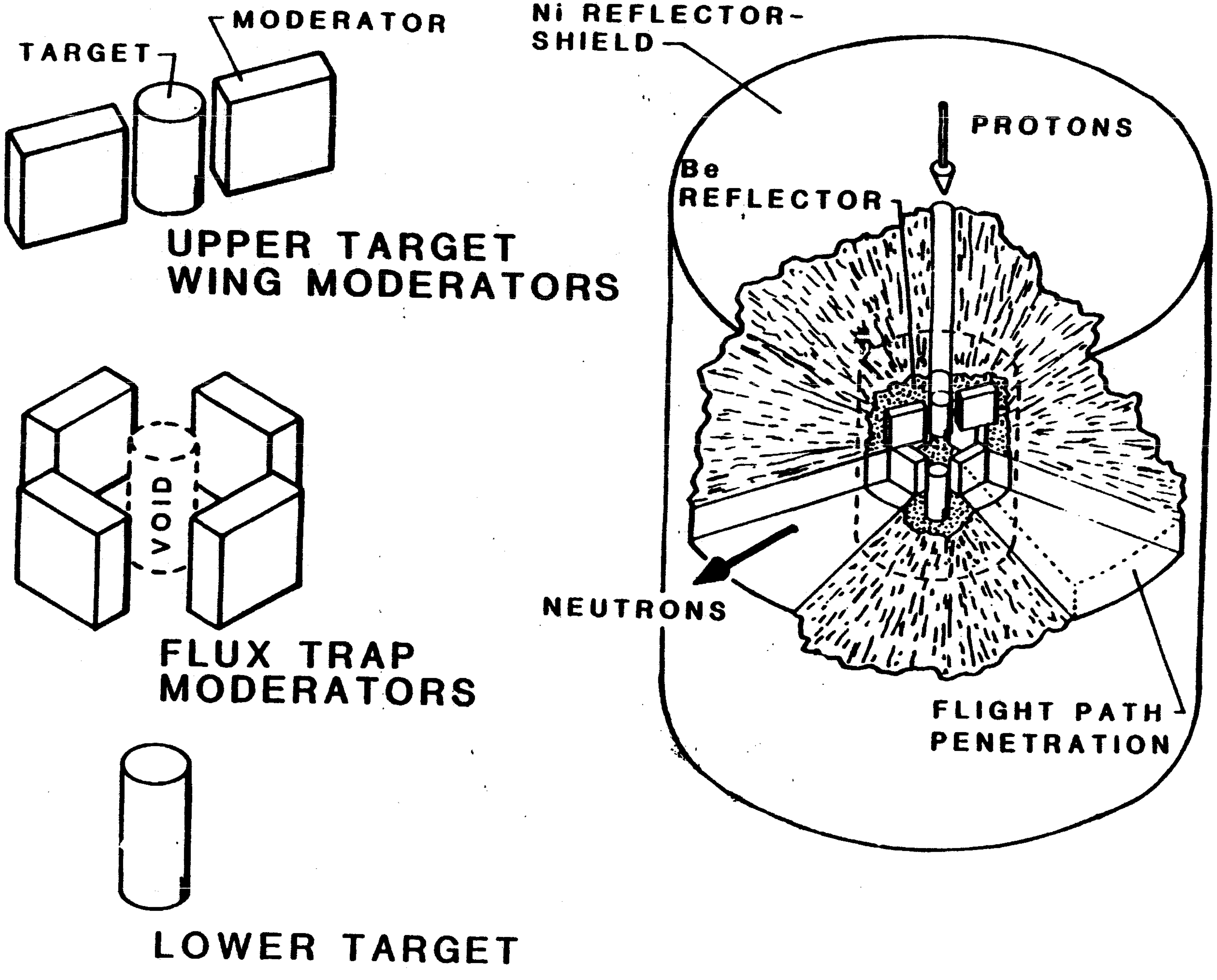
Fig. 9. Calculated neutron spectra from the 3-cm diameter.x 7.5-cm long WNR tungsten target, including the stainless steel cooling jacket and water cooling channels.

Fig. 10. Calculated neutron spectra from 3-cm diameter x 7.5-cm long WNR targets of Berylium, Copper, Tungsten and depleted

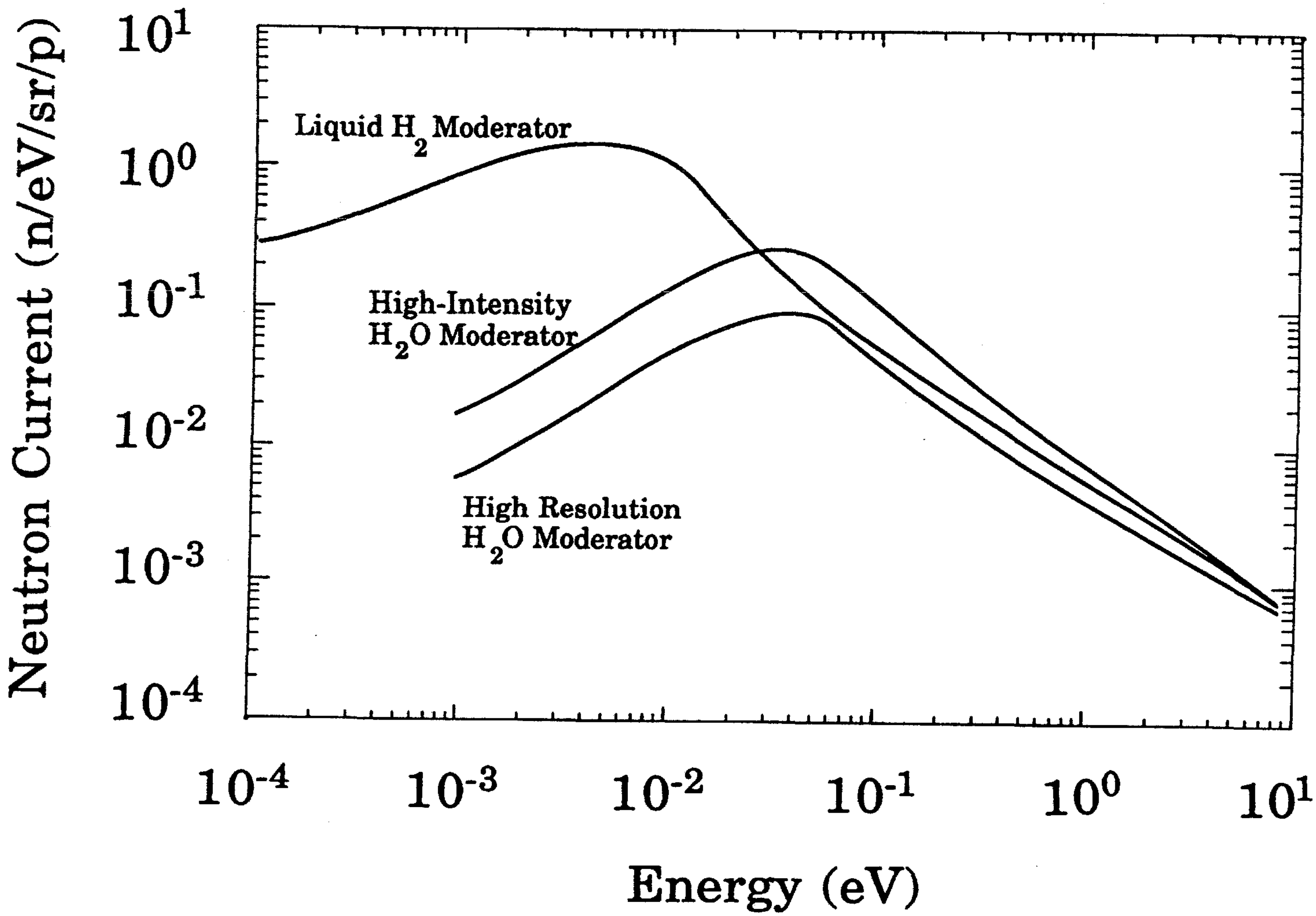
Uranium. These calculations model both the target and the stainless steel cooling jacket and water bath.



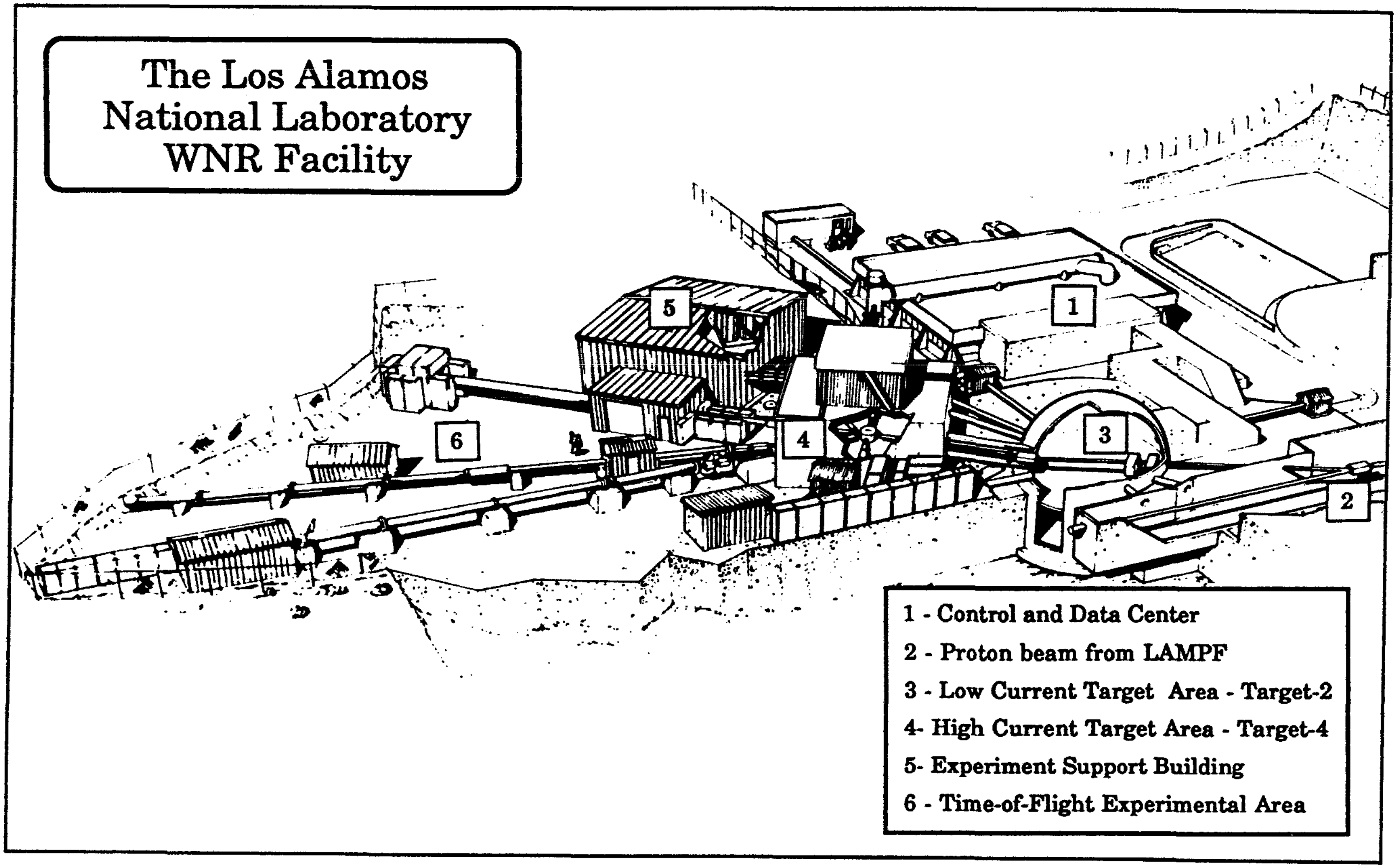
"The Los Alamos National Laboratory Spallation Neutron Sources," P. W. Lisowski, C. D. Bowman, and S. A. Wender Fig. 1.



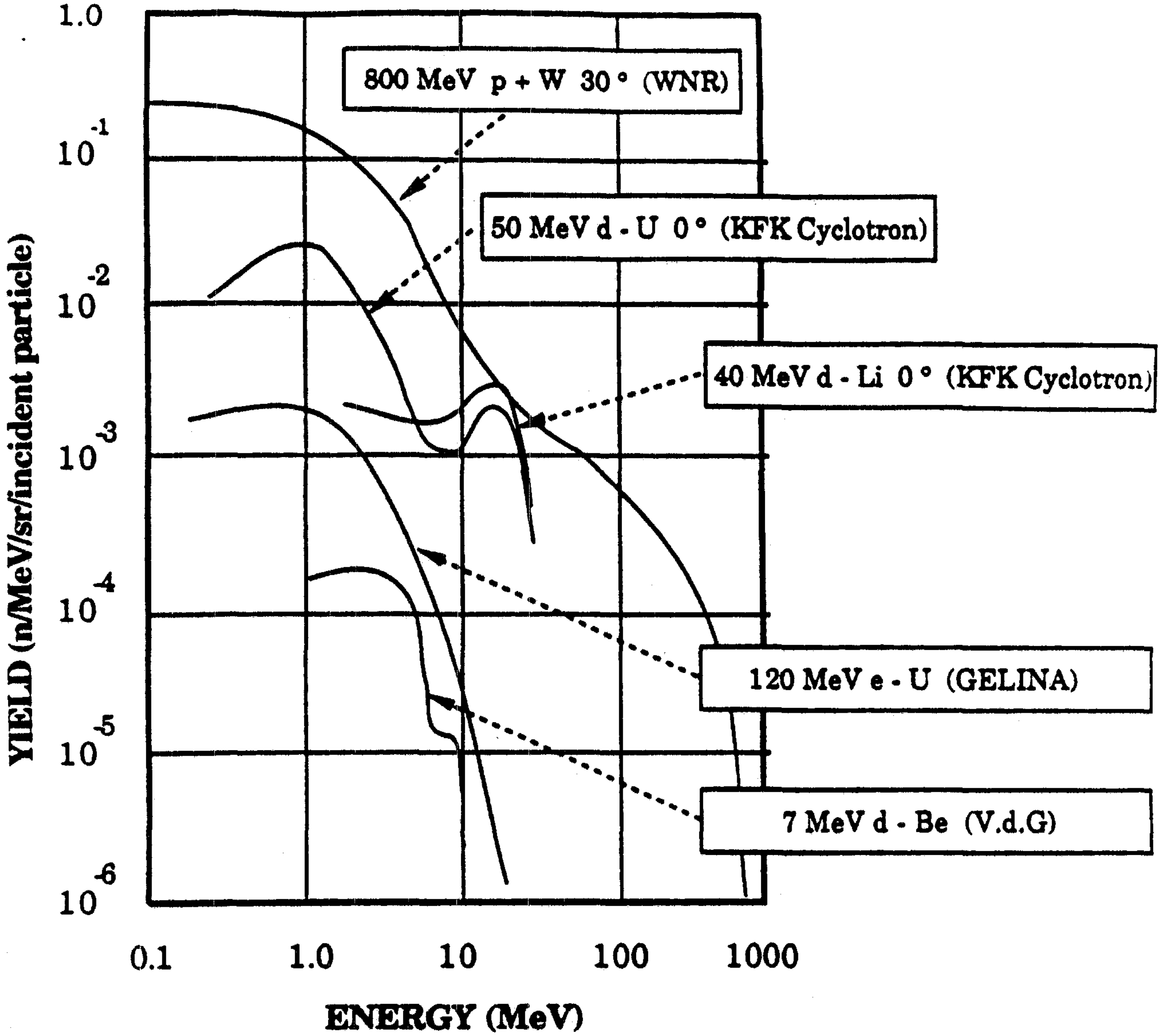
"The Los Alamos National Laboratory Spallation Neutron Sources," P. W. Lisowski, C. D.



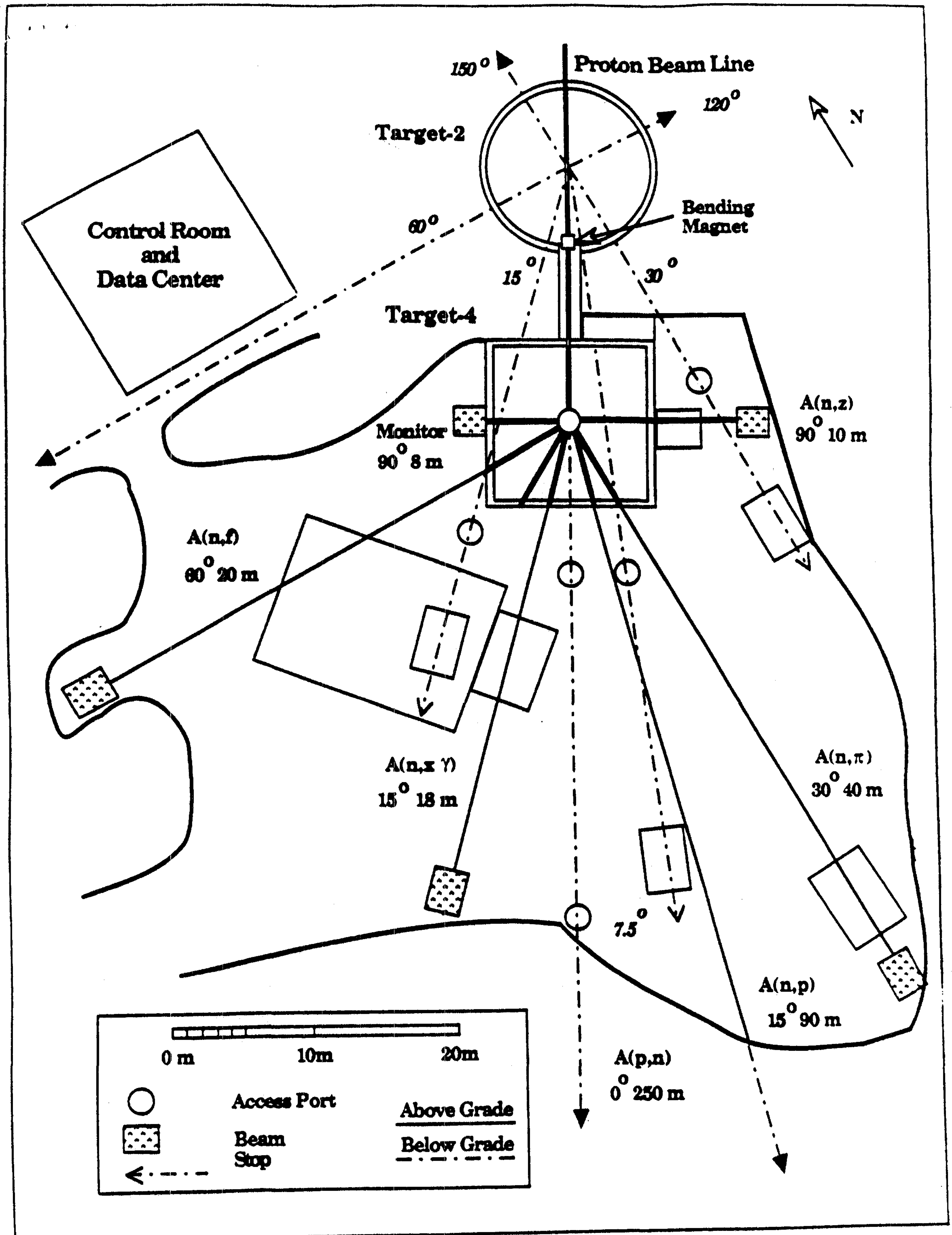
"The Los Alamos National Laboratory Spallation Neutron Sources," P. W. Lisowski, C. D. Bowman, G. J. Russell, and S. A. Wender Fig. 3.



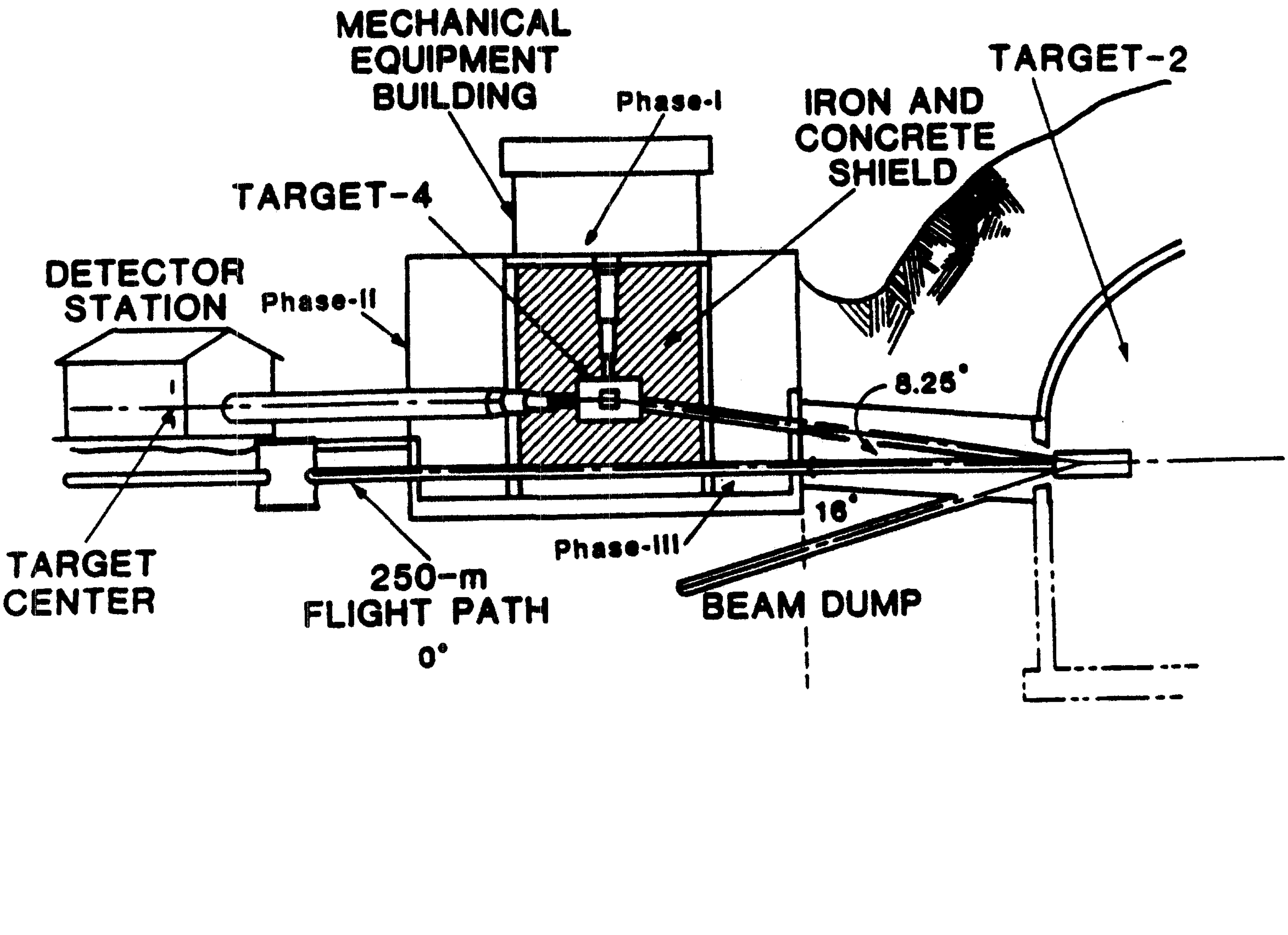
"The Los Alamos National Laboratory Spallation Neutron Sources," P. W. Lisowski, C. D. Bowman, G. J. Russell, and S. A. Wender Fig. 4.



"The Los Alamos National Laboratory Spallation Neutron Sources," P. W. Lisowski, C. D. Bowman, and S. A. Wender Fig. 5.

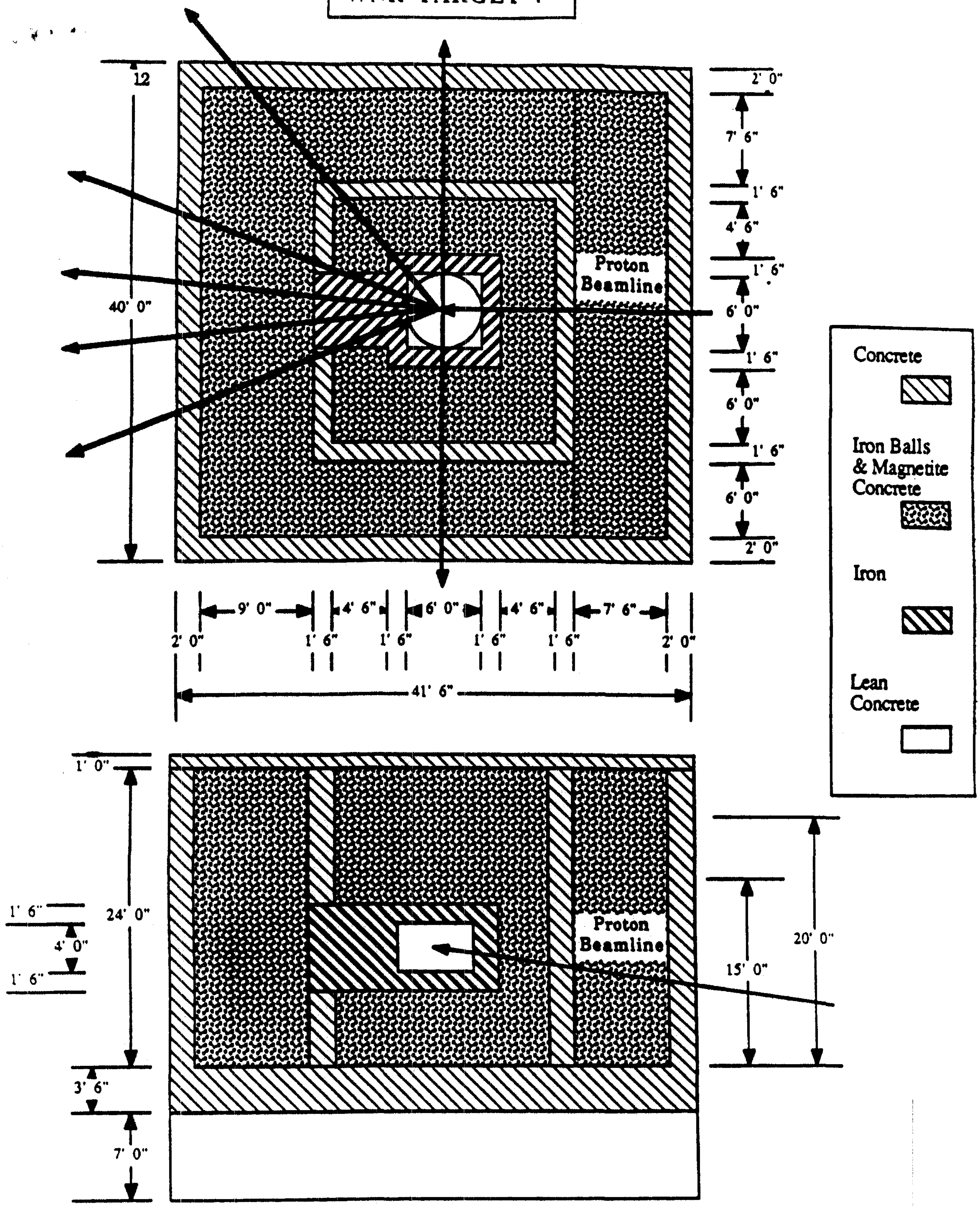


"The Los Alamos National Laboratory Spallation Neutron Sources," P. W. Lisowski, C. D.

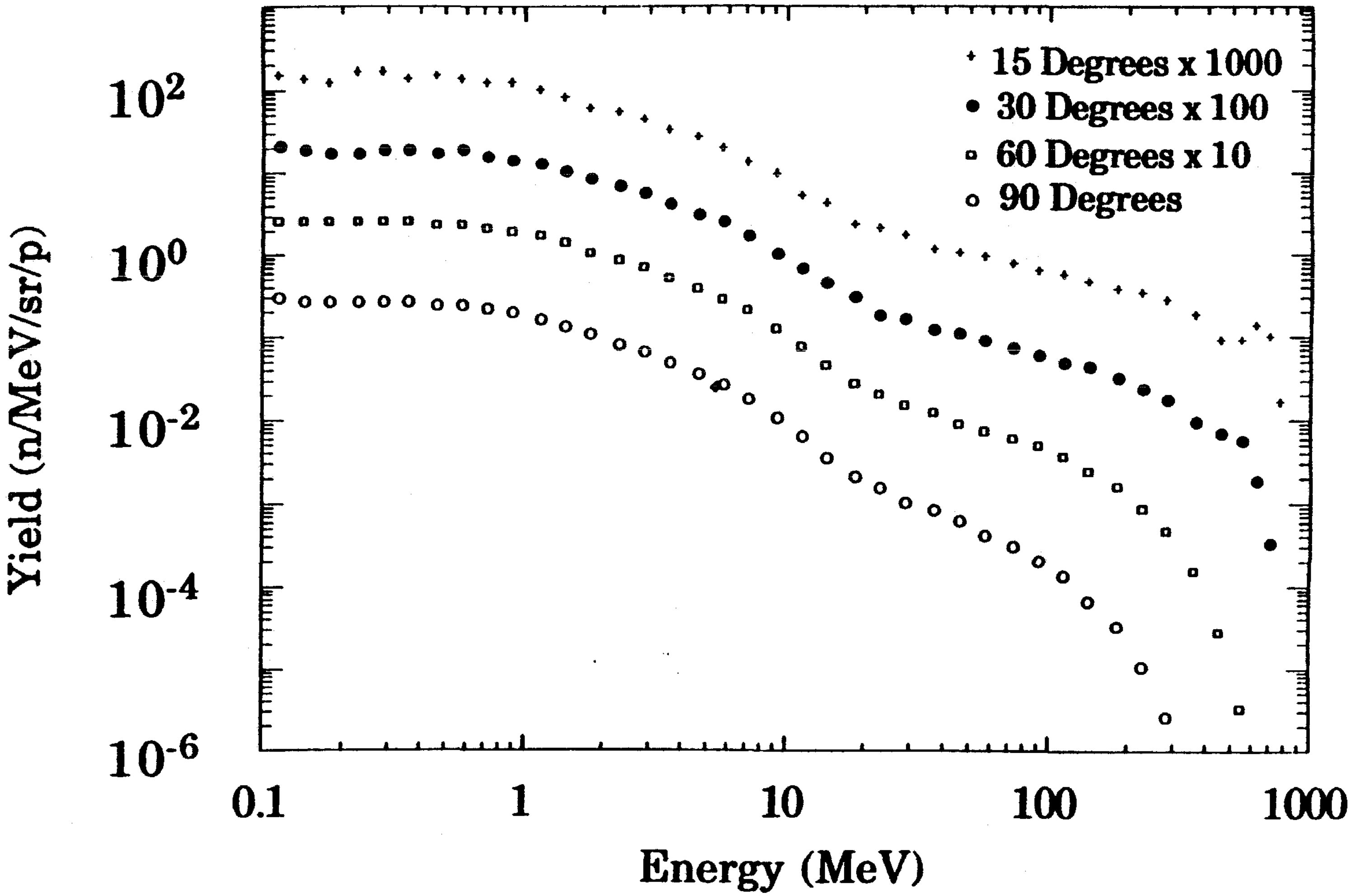


"The Los Alamos National Laboratory Spallation Neutron Sources," P. W. Lisowski, C. D. Bowman, and S. A. Wender Fig. 7.

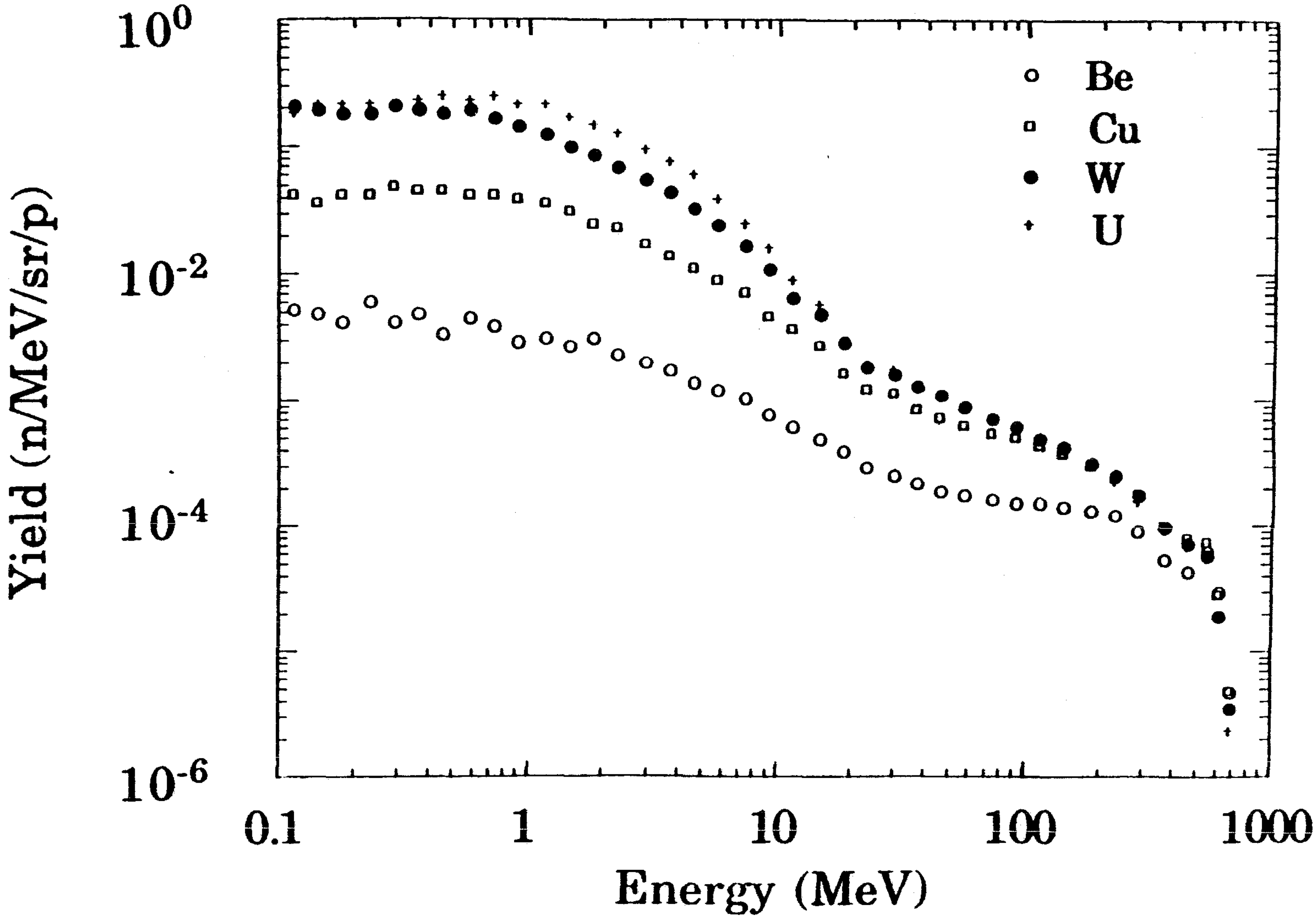
WNR TARGET-4



"The Los Alamos National Laboratory Spallation Neutron Sources," P. W. Lisowski, C. D. Bowman, and S. A. Wender Fig. 8.



"The Los Alamos National Laboratory Spallation Neutron Sources," P. W. Lisowski, C. D. Bowman, and S. A. Wender Fig. [illegible]



"The Los Alamos National Laboratory Spallation Neutron Sources," P. W. Lisowski, C. D. Bowman, and S. A. Wender, Fig. 10